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Shear failure criterion for RC T-beams

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ABSTRACT

The paper is concerned with the development of a failure criterion capable of accurately predicting the shear capacity of reinforced concrete T-beams while correctly accounting for the beneficial effect of the increase of the compressive zone due to the presence of flanges. The development of the subject criterion is based on an alternative design method (the compressive force path method) that leads to predictions of reinforced concrete structural behaviour and design solutions considerably different compared to those of the current design codes without however compromising structural performance requirements (mainly associated with ductility and strength). The validity of the proposed failure criterion is verified through a comparative study of the calculated values with their experimentally-established counterparts obtained from an extensive literature survey. Through this comparative study it is demonstrated that the predictions of the proposed criterion provide a closer fit to the available experimental data than their counterparts obtained from the design codes considered.

1. Introduction

Experimental information, which is used in the work presented herein, shows that reinforced concrete (RC) beams with a T-shaped cross section exhibit values of shear capacity which are higher, often by a significant amount, than those characterising RC beams with a rectangular cross section [1]. Such behaviour can be attributed to the increase of the beams' compressive zone due to the presence of the flange, the effect of which on shear capacity is not allowed for in current design practice. This is because, in accordance with the simplified beam theory which underlies shear design methods, any increase in shear capacity due to the increase of the width of the compressive zone is, to a large extent, counteracted by the decrease of the shear stresses within the flange as they spread along the flange width (see Fig. 1).

Therefore, there is an inherent difficulty in allowing for the flange's effect on shear capacity without a modification of the concepts underlying shear design methods. And yet, allowing for this effect may lead to a reduction of the amount of transverse reinforcement required to safeguard against shear failure. This may be true, not only when concrete in the presence of transverse reinforcement is considered to contribute to shear capacity (ACI 318 2014 [2]), but also when the concrete's contribution is ignored (EC2 2004 [3]). In the latter case, if the flange's effect on shear capacity were allowed for, the code criterion for specifying reinforcement may not be fulfilled and, therefore, a nominal amount of transverse reinforcement may be sufficient.

In view of the above, the aim of the present work is the development of a failure criterion which allows for the effect of the compressive zone's size on shear capacity. The work will be based on concepts which underlie the Compressive Force Path (CFP) theory [4], since this is the only theory proposed to date which links the causes of an RC beam's failure to the stress conditions in the compressive, rather than the tensile zone. The validity of the proposed criterion will be verified through a comparison of its predictions with experimental data obtained from the literature. The comparison will also include the values predicted by current codes (ACI 318 2014 [2], EC2 2004 [3]), as well as an empirical formula, which has been developed so as to allow for the effect of the compressive zone's shape and size on shear capacity and included in the guidance for “design and detailing of concrete structures for fire resistance” of The Institution of Structural Engineers, London 1978 [5].

2. Background

2.1. Shear resistance and force transfer

In accordance with the CFP theory [4], the shear resistance of the tensile zone of RC beams becomes negligible, if any, after the formation of flexural and/or inclined cracks. This is because cracking diminishes the shear stiffness of concrete and causes stress redistribution towards the stiff crack-free concrete of the compressive zone; thus, the latter becomes the sole contributor to the beam's shear resistance. Moreover, it has been demonstrated [4] that such behaviour is compatible with the experimentally-established behaviour of concrete as a material as regards both its stress-strain behaviour and its cracking mechanism, the

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Nomenclature

a_v	shear span
b, b_w	width of beams web
d	effective depth
h_f	flange height
ρ	ratio of tensile longitudinal reinforcement
f_t	strength of concrete in direct tension
f_{yv}	yield stress of transverse reinforcement
A_{sv}	cross sectional area of transverse reinforcement within a length of 2d extending symmetrically on either side of the location of 2.5d from the closest beam support.
ΔM	bending moment increment
ΔT	bond force
V	shear force
$T_{II,1}$	maximum transverse tensile force sustained by concrete in the compressive zone at a distance of 2.5d from nearest support for beams with a rectangular cross section and $a_v/d > 2.5$.
$T_{II,1f}$	portion of $T_{II,1T}$ (see below) developing in flange
$T_{II,1T}$	$T_{II,1}$ for a T-beam with $a_v/d > 2.5$.
$V_{II,1}$	maximum shear force sustained at cross section at a distance of 2.5$d$from nearest support for beams with a rectangular cross section and $a_v/d > 2.5$.
$V_{II,1,T}$	$V_{II,1}$ for a T-beam with $a_v/d > 2.5$.

Fig. 1. Shear stress distributions for (a) rectangular and (b) T sections.

latter involving crack extension in the direction of cracking and opening in the orthogonal direction, thus precluding any shear movement of the crack faces that may be resisted by aggregate interlock and dowel action as widely assumed.

In view of the above, internal force transfer is accomplished by the compressive zone through a beam-like action mechanism schematically described in Fig. 2. From the figure, it can be seen that, under the action of the bond force, ΔT, developing at the interface between concrete and flexural steel, concrete cantilevers (such as that indicated in Fig. 2(a)) which form between successive flexural or inclined cracks, subject the compressive zone to a momentΔM (see Fig. 2(b)) which transfers the shear force V acting on the right-hand side of the portion to which the cantilever is fixed to the left-hand side (see Fig. 2(c)). Moreover, it has been shown that the presence of triaxial compressive-stress conditions developing for purposes of transverse deformation compatibility enables the compressive zone to sustain alone the total action of V [4], commonly assumed to be sustained by the beam cross section.

2.2. Shear failure and underlying causes

In accordance with the experimental findings of Kani (1964) [6], RC beams, without transverse reinforcement, with shear span-to depth ratios (a_v/d) ranging between 1 and a value (dependent on the reinforcement ratio ρ) of the order of 5, exhibit load carrying capacities smaller than that corresponding to flexural capacity (see Fig. 3). The causes of such 'premature' loss of load-carrying capacity are attributed

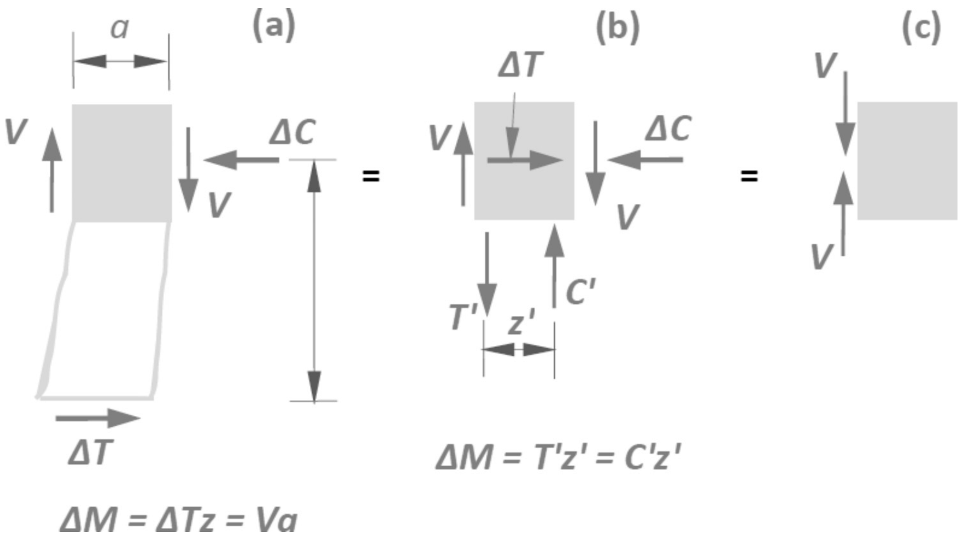

Fig. 2. Mechanisms of load transfer through cantilever action.